International Conference on Applied Energy 2021
September 4-8, 2021, Matsue, Japan
Paper ID: 40

The Carbon Footprint of Pacific Oyster Farming in China

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ABSTRACT

Bivalve shellfish farming is expected to be performed as the effective mitigator of the growing pressure for global animal protein demand. Carbon emission reduction in the whole farming process of the bivalve shellfish has great potential in reducing carbon emissions in food production in the future. However, the hatchery stage of oyster, with high energy input, may be a high carbon emission process and necessitates effective carbon emission reduction. This study uses life cycle assessment (LCA) to analyze the carbon footprint of the farming of Pacific oyster (*Crassostrea gigas*), a shellfish with the largest farming yield in the world, in Fujian province in China. The results show that the total carbon footprint, from cradle to gate is 70.81 kgCO_2-eq/tonne fresh oyster, which suggested that oyster farming perform favorably against livestock farming for protein products and can justifiably be promoted as a low-carbon food product. Hatchery culture contributed 62.2% of the total carbon emission. The feed production in the hatchery culture stage, account for about 2.27 % of carbon emission, were not the major emission factor. Carbon emission form energy consumption and material inputs are about half and half. The carbon footprint of Pacific oyster can be reduced by employing energy-conserving transport technology and utilizing renewable energy. The improvements could be helpful for sustainable production of Pacific oyster farming.

Keywords: Pacific oyster farming, Life cycle assessment, Carbon emission

1. *Introduction*

The production of animal protein is associate with high greenhouse gas (GHG) emissions. However, as projected by The Food and Agriculture Organization (FAO)， the world's human population will reach 9.8 billion by 2050 and will require more than 500 Mt of meat per year for food [1]. Moreover, the global food production systems will generate a more impactful environmental footprint by 2050 [2]. Livestock meat, though nutrient rich, has a limited potential to solve the contradiction between expanding production and reducing carbon emissions for the ecological limitation and strong CO_2 emissions. The Bivalve shellfish farming is one of the most promising way to fill the food gap and mitigate the global climate change. The farming of shellfish has very low carbon emission and the requirement for freshwater and terrestrial land space for shellfish cultivation is minimal [3, 4]. What's more, over 1,500,000 km^2 are potentially suitable for shellfish farming across the globe sea area and it has strong expansive potential [5]. However, such a large among of shellfish farming would strongly depend on artificial intensive seeds breeding, which may require high inputs of energy to pure seawater, aeration, and grow algal feed for juvenile bivalves and brood stock, and chemical drugs are frequently used. These processes are likely be the major contributors to GHG-emissions from shellfish farming systems but remain largely unquantified. For some marine farming shellfish species such as blue mussel that depend on seedlings in natural sea areas has been well studied and proved has low carbon footprint (form cradle to gate) [2, 6, 7]. However, the carbon footprint of oysters, that has the largest production amount among farmed shellfish, are much less known, especially the hatchery culture stage. To address this gap in knowledge, the present study will focus on the carbon

Selection and peer-review under responsibility of the scientific committee of the 13th Int. Conf. on Applied Energy (ICAE2021).

footprint of the farming Pacific oyster (*Crassostrea gigas*) in China who has the largest oyster farming yield.

As the implementation of the reform and opening-up policy, China's farmed oyster production has been rapidly growing and reached a new high of 5.23 million tons in 2019 which accounted for 85.31% of the world production [8]. Pacific oyster accounts for more than 68% of oyster farming in China and mainly depend on the triploid seedlings production in Fujian. The "from cradle to gate" carbon footprint of Pacific oyster farming were analysis using life cycle assessment (LCA). We also compared the results generated with estimates of GHG-release from published land-based livestock production on a kg CO_2-eq per kg protein basis. The analysis will be helpful to improve understanding of where and how GHG emissions arise in oyster farming process, so that future studies can focus on developing cost-effective ways of improving performance and reducing emissions.

2. *Material and methods*

Primary data that cover flue use, electricity use and raw material input were collected using questionnaires to guide interviews. The information was from 6 seedling plants in Fujian and 3-10 farmers from each province, from May to August 2021. After collection, the data were transferred to a single database so that they could be interpreted. The scope of this carbon footprint is from 'cradle to gate', including all life cycle stages of the Pacific oyster until they were transported to the market for distribution and detail farming stages are showed in Fig. 1. Emissions from building and production of capital equipment such as vessels, factory, machinery and their maintenance are not considered in this study. Material input were divided by service time to average for each round of farming.

In China, the oysters are mainly farmed using the surface longline method. Seedlings are cultured by intensive production in the factory. The production of unicellular algae for feed for juvenile oysters and brood stock was needed in the hatchery culture stage.

After about 40 days culture (from brood stock conditioning to the juvenile oysters or larvae that meet the commercial seed specifications), the larvae should be transport by a refrigerated truck for 1100 km on average to the farm area. After being transported to farm area, the juvenile oysters are graded according to size, and hanged to the sea aera for growth. It is managed once a week on average for cleaning the attached organisms, adjusting the density, and adding additional float as the weight increases. After about 18 months culture, the oyster could reach marketable size at about 200-300g/ind. Then it is harvested transported by a refrigerated truck for 50 km on average to the market.

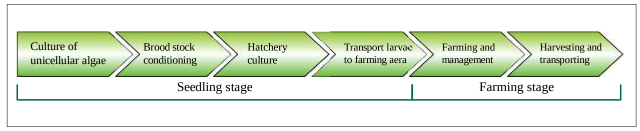

Fig. 1. Sketch map of Pacific oyster farming process.

3. *Results and discussion*

3.1 Carbon footprint analysis

The materials and energy input list from the cradle to the gate was shown in Table 1. The "from cradle to gate" carbon footprints were calculated to be 70.81 kg CO_2-eq per tonne of fresh oysters (Fig. 2). And 64.46% of the carbon footprint is from seedling stage (45.65 kg CO_2-eq per tonne), which is mainly contributed by nylon rope use (23.09. kg CO_2-eq per tonne) that accounting for 32.61% of total carbon footprint. Diesel use in transportation makes the second large contribution (19.42%). What is not we suspected before is that feed or unicellular algae production only account for 2.27% (1.61 kg CO_2-eq per tonne) of total carbon footprint, which was not the main emission factor.

The farming stage contributed 35.53% of carbon footprint. The diesel use (19.08% of total carbon footprint) makes the largest contribution, which is from vessel consumption during the management process and transportation. The polyethylene float ball use (11.58%) makes the second large contribution which is followed by polypropylene rope (4.88%) that used as main line of a buoyant raft.

The top five factors of carbon emissions are as: diesel, nylon rope, polyethylene float ball, electricity, and polypropylene rope use. The diesel was mainly used in transportation and vessel consumption in the management of farmed oyster. For the total carbon footprint, material and energy inputs emission are almost half and half. Using renewable energy and law carbon footprint materials could effectively reduce the carbon footprint. If we replace nylon rope with same weight and size polypropylene rope, a very common rope in the market, the carbon emission in this part could be reduced to 4.97 kg CO_2-eq per tonne and the total carbon footprint is 52.70 kg CO_2-eq per tonne. Considering that polypropylene rope costs more than twice as much as nylon rope and this usage is

Table 1. Energy and material input in oyster faming

	Input	Amount	Unit	Database of emission factor
Culture of unicellular algae	Electricity	1.43	kWh/tonn	CLCD
	Glass	4.00E-4	kg/tonne	CLCD
	Acrylic barrels	8.00E-3	kg/tonne	ELCD 3.0
	Polyethylene	0.01	kg/tonne	ELCD 3.0
	NaClO	0.04	kg/tonne	CLCD
	NaNO3	0.03	kg/tonne	CLCD
	Na2O·2SiO2	7.20E-3	kg/tonne	CLCD
	FeC6H5O7	1.40E-3	kg/tonne	ignore
	NaH2PO4	1.60E-3	kg/tonne	ignore
Hatchery culture	Electricity	6.2	kWh/tonn	CLCD
	Coke	1.56	kg/tonne	CLCD
	Diesel	3.35	kg/tonne	CLCD
	Nylon rope	2.4	kg/tonne	ELCD 3.0
	NaClO	0.07	kg/tonne	CLCD
Farming stage	Polyethylene	4	kg/tonne	ELCD 3.0
	Polypropylene	1.67	kg/tonne	ELCD 3.0
	Diesel	0.33	kg/tonne	CLCD

3.2 Comparison with other foods

When comparing the carbon footprint of Pacific oyster farming as other food productions, it was based on a kg CO_2-eq per kg protein basis. Other common protein sources competing with oysters include beef, milk, pork, and eggs. The protein content of oyster is 55.98 % of dry weight of soft tissue [9]. As reported in Shao et al. [10], 1 kg oyster could produce about 39.97 g soft tissue (dry weight). Accordingly, 1 kg protein produced by oyster would emission 3.16 kg CO_2-eq. This emission is far less than that in beef, milk, pork and even eggs, which is 103.5±42.14, 39.72±13.20, 32.09±8.14, and 19.37±7.15 kg CO_2-eq per kg protein, respectively [11]. The result suggested that oyster farming perform favorably against livestock farming for protein products and can justifiably be promoted as a low-carbon food product.

4. *Conclusions and suggestions*

This study considered the "cradle to farm gate" carbon footprint of Pacific oyster framing. The results suggest that oyster farming perform favorably against livestock farming for protein products and can justifiably be promoted as a low-carbon food product. Meanwhile efforts to further reduce the impacts on climate change should focus on increasing renewable energy proportion and using low carbon footprint materials (such as use

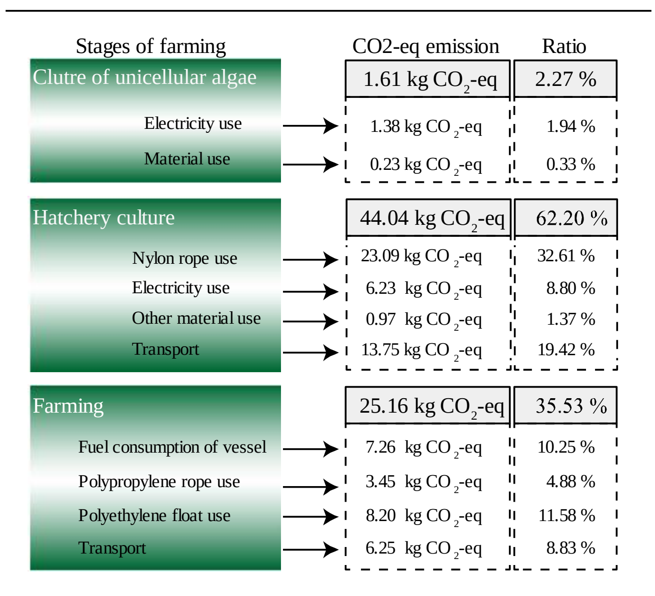

Fig. 2. Cradle to farm gate carbon footprint summary for Pacific oyster (kg CO_2-eq per tonne of oyster)

disposable and unrecyclable, farmers are more inclined to use nylon ropes. This change for carbon emission reduction may require government' guidance and subsidy policy support.

polypropylene rope to replace the nylon rope). On the other hand, there several limitations in this study and could be further complete in the future research. (1) The construction and maintenance of the vessels and factory and other equipment are outside the scope of this study, which could be refined in the future studies. (2) Considerable differences are seen among the interviewed farmers contributing data to this study. This may be a natural variance due to different sea area conditions and farming methods, and nutrient levels. It could be further investigated by broadening the scope of the investigation. (3) This research only gives a “from cradle to gate” analysis. A “from cradle to grave” carbon footprint research, including consuming or cooking process and byproduct processing process will be more instructive to guide oyster farming expansion in the future.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support for this research received from the National Natural Science Foundation of China (42022046 and 51806251), and the Key Special Project for Introduced Talents Team of Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou) (GML2019ZD0401 and GML2019ZD0403).

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